

The Voting Farm  
A Distributed Class for Software Voting

Vincenzo De Florio  
Universiteit Antwerpen  
Department of Mathematics and Computer Science  
MOSAIC research group  
Middelheimlaan 1, B-2020 Antwerpen

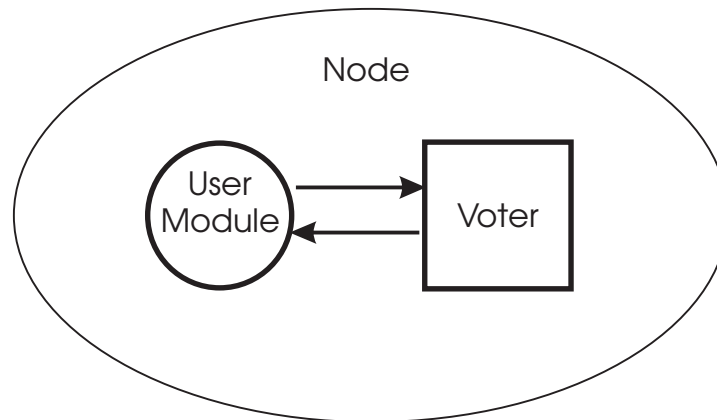
(version revised on April 29, 2015)

### 1. VotingFarmTool.

This document describes a class of C functions implementing a distributed software voting mechanism for EPX [11, 12] or similar message passing multi-threaded environments. Such a tool may be used for example, to set up a restoring organ [9] i.e., an NMR (i.e.,  $N$ -module redundant) system with  $N$  voters.

In order to describe the tool we start defining its basic building block, the *voter*.

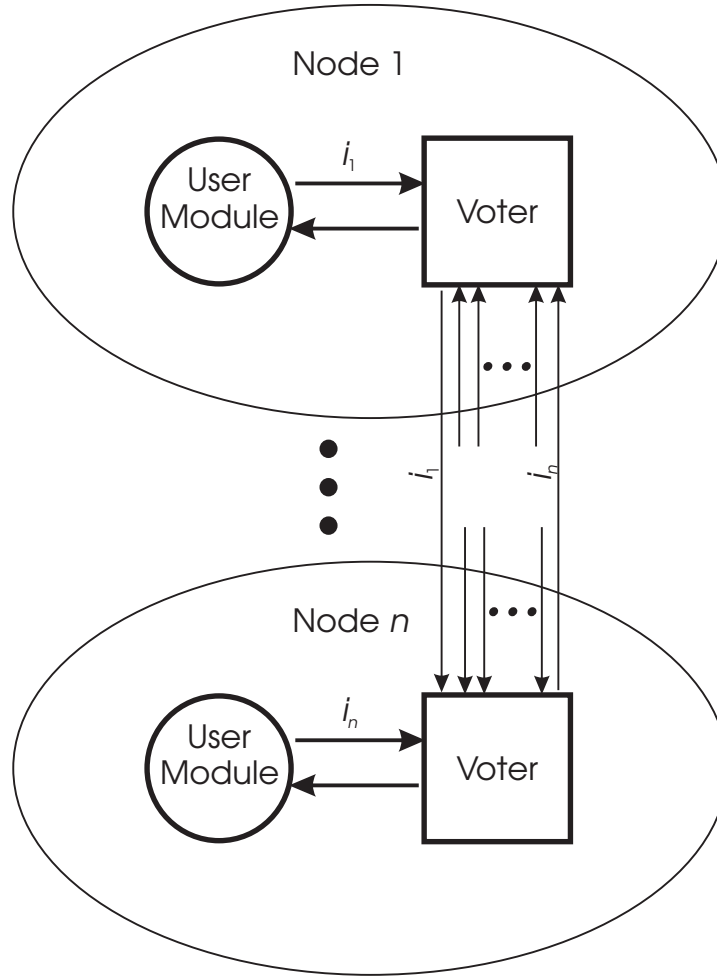
A voter is defined as a software module connected to one user module and to a farm of fellow voters arranged into a cliqué.



**Figure 1.** A user module and its local voter.

By means of the functions in the class the user module is able:

- to create a static “picture” of the voting farm, needed for the set up of the cliqué;
- to instantiate the local voter;
- to send input or control messages to that voter.



**Figure 2.** The architecture of the voting farm: each user module connects to one voter and interacts only with it. In particular, the user module sends its local voter only one input value; the voter then broadcasts it across the farm; then it receives  $N - 1$  messages from its fellows so to be able to perform the voting.

No interlocutor is needed other than the local voter. The other user modules are supposed to create coherent pictures and instances of voters on other nodes of the machine and to manage consistently the task of their local intermediary. All technicalities concerning the set up of the cliqué and the exchange of messages between the voters are completely transparent to the user module. More information about the voting farm may be found in [6, 7, 8].

In the following the basic functionalities of the VotingFarm class will be discussed, namely how to set up a “passive farm”, or a non-alive (in the sense of [4, 5]) topological representation of a yet-to-be-activated voting farm; how to initiate the voting farm; how to control the farm.

```

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2. Prologue: headers, global variables, etc.

```

#define VF_MAX_NTS 16 /* size of stacks  $\equiv$  max value for  $N$  */
#define VOTING_FARMS_MAX 64 /* max number of simultaneous active voting farms */
#define VF_MAX_INPUT_MSG 512 /* max size of an input message */
#define VF_MAX_MSGS 10 /* max size of the message buffer */
#define VF_EVENT_TIMEOUT 10 /* Select time-out is 10 seconds */
#define NO 0
#define YES 1

#define E_VF_OVERFLOW -1 /* error conditions */
#define E_VF_CANT_ALLOC -2
#define E_VF_UNDEFINED_VF -3
#define E_VF_WRONG_NODE -4
#define E_VF_GETGLOBID -5
#define E_VF_CANT_SPAWN -6 /* CreateThread error */
#define E_VF_CANT_CONNECT -7 /* ConnectLink error */
#define E_VF_RECVLINK -8 /* RecvLink error */
#define E_VF_BROADCAST -9 /* Invalid input message - can't broadcast */
#define E_VF_DELIVER -10 /* Invalid output LinkCB.t - can't deliver */
#define E_VF_BUSY_SLOT -11 /* Duplicated input message */
#define E_VF_WRONG_VFID -12
#define E_VF_WRONG_DISTANCE -13
#define E_VF_INVALID_VF -14
#define E_VF_NO_LVOTER -15 /* exactly one voter is mandatorily needed */
#define E_VF_TOO_MANY_LVOTERS -16 /* exactly one voter is mandatorily needed */
#define E_VF_WRONG_MSG_NB -17 /* wrong number of messages */
#define E_VF_SENDLINK -18 /* SendLink error */
#define E_VF_INPUT_SIZE -19 /* inconsistency in the size of the input */
#define E_VF_UNDESCRIBED -20 /* undescribed vf object */
#define E_VF_INACTIVE -21 /* inactive vf object */
#define E_VF_UNKNOWN_SENDER -22 /* inconsistency—sender unknown */
#define E_VF_EVENT_TIMEOUT -23 /* a Select reached time-out */
#define E_VF_SELECT -24 /* a Select returned an index out of range */
#define E_VF_WRONG_ALGID -25 /* AlgorithmID out of range */
#define E_VF_NULLPTR -26 /* A pointer parameter held  $\Lambda$  */
#define E_VF_TOO_MANY -27 /* Too many opened voting farms */

#define VF_ERROR_NB 28 /* number of errors, plus one */
#define VF_MAX_FARMS 64 /* maximum number of farms available */ /* voting algorithms */
#define VFA_EXACT_CONCENSUS 0
#define VFA_MAJORITY 1
#define VFA_MEDIAN 2
#define VFA_PLURALITY 3
#define VFA_WEIGHTED_AVG 4
#define VFA_SIMPLE_MAJORITY 5
#define VFA_SIMPLE_AVERAGE 6
#define VF_SUCCESS 1
#define VF_FAILURE 0

#define VF_NB_ALGS 7 /* nb of algorithms plus one */
/* default value for the  $\epsilon$  threshold of formalized majority voting */
#define VFD_EPSILON  $5 \cdot 10^{-5}$ 
#define VFP_INITIALISING 0
#define VFP_CONNECTING 1

```

```
#define VFP_BROADCASTING 2
#define VFP_VOTING 3
#define VFP_WAITING 4
#define VFP_FAILED 5
#define VFP_QUITTING 6
```

3. Two global variables have been supplied for the user to query the error status of the application and the name of the function which experienced the error. Their definition constitutes the main part of the following section.

```

⟨ Global Variables and # include's 3 ⟩ ≡
#include <stdio.h>
#include <stdlib.h>
#include <stdarg.h>
#include <sys/root.h>
#include <sys/logerror.h>
#include <sys/link.h>
#include <sys/select.h>
#include <sys/time.h>
#include <sys/thread.h>
#ifdef SERVERNET
#include "server.h"
#endif /* SERVERNET */
int VF_error; /* global variable for storing the error condition */
static double  $\epsilon$  = VFD_EPSILON;
static double ScalingFactor = 1.0;
int once = 1;
static int VF_RequestId(int, int, int);
typedef struct {
    unsigned char *item;
    int item_nr;
} cluster_t; /* A flag is attached to each object so that the object can be logically "deleted" from
the list simply setting its status to NOT_PRESENT. Once the list is created, all its elements are labeled
as PRESENT; as the execution goes by, elements are "logically" removed from the list changing their
status to NOT_PRESENT. */
typedef unsigned char flag;
typedef struct {
    void *object;
    flag status;
} value_t; /* This part has been added in V1.5. It defines a set of (redefineable) symbolic constants
representing upper limits for pre-allocated areas used exclusively in the static version of the tool. */
#ifdef VF_STATIC_MAX_INP_MSG
#define VF_STATIC_MAX_INP_MSG 64
#endif
#ifdef VF_STATIC_MAX_LINK_NB
#define VF_STATIC_MAX_LINK_NB 16
#endif
#ifdef VF_STATIC_MAX_VOTER_INPUTS
#define VF_STATIC_MAX_VOTER_INPUTS 20
#endif
#ifdef STATIC
#define AllocationClassstatic
    LinkCB_t * st_links[VF_STATIC_MAX_LINK_NB];
    Option_t st_options[VF_STATIC_MAX_LINK_NB];
    double st_VFA_sum; /* used in VFA algorithms */
    double st_VFA_weight[VF_STATIC_MAX_INP_MSG];
    double st_VFA_squaredist[VF_STATIC_MAX_INP_MSG * VF_STATIC_MAX_INP_MSG];
    cluster_t st_clusters[VF_STATIC_MAX_VOTER_INPUTS];
    void *st_voter_inputs[VF_STATIC_MAX_VOTER_INPUTS];

```

```

    char st_chars[VF_STATIC_MAX_VOTER_INPUTS];
    value_t st_VFA_v[VF_STATIC_MAX_INP_MSG];
    char st_voter_inputs_data[VF_STATIC_MAX_VOTER_INPUTS][VF_STATIC_MAX_INP_MSG];
#else
#define AllocationClass
#endif
    unsigned char st_VFA_vote[VF_STATIC_MAX_INP_MSG];

```

This code is used in section 1.



**4. Voting Farm Declaration.** The whole *VotingFarm* class is built upon type **VotingFarm\_t**, which plays the same role as the type **FILE** in the standard class of C functions for file management: it offers the user a way to refer to some object from an abstract point of view, masking him/her from all unneeded information concerning its implementation. All a user needs to know is that, in order to use a voting farm, he/she has first to declare an object like follows: **VotingFarm\_t** \* *vf*;

The newly defined *vf* variable does not describe any valid voting farm yet; it is simply a pointer with no object attached to it, exactly the same way it goes for a **FILE** \**fp* variable which has not been *fopen*'d yet. For that a special function is supplied: *VF\_open*, which is discussed in the next subsection.

Each user module which needs to use a voting farm should declare a **VotingFarm\_t** \* variable.

⟨ Voting Farm Declaration 4 ⟩ ≡

```
typedef struct {
    int vf_id;
    int vf_node_stack[VF_MAX_NTS];
    int vf_ident_stack[VF_MAX_NTS];
    LinkCB_t * pipe[2];
    int N;
    int user_thread;
    int this_voter;
    double (*distance)(void *, void *);
    flag broadcast_done;
    flag inp_msg_got;
    flag destroy_requested;
#ifdef SERVERNET
    RTC_Thread_t rtc;
#endif
} VotingFarm_t;
static int VF_voter(VotingFarm_t *);
int VF_add(VotingFarm_t *, int, int);
void VF_perror(void);
#ifdef STATIC
VotingFarm_t Table[VF_MAX_FARMS];
#endif
void *memdup(void *p, size_t len)
{
    void *q = malloc(len);
    if (q) memcpy(q, p, len);
    return q;
}
```

This code is used in section 1.

**5.** In the above, *vf\_id* is a unique integer which identifies a voting context, *vf\_node\_stack* is a stack of node ids (a voter thread will be spawned on each of them), *vf\_ident\_stack* is a stack of thread id, *N* is a stack pointer (only one stack pointer is needed because the two stacks evolve in parallel), and *user\_thread* is the thread id of the caller (or user) module. *pipe* is a couple of pointers to **LinkCB\_t**, used to communicate between the user module and the local voter. *this\_voter* is the entry of the current voter.

**6. Voting Farm Definition.** A voting farm variable *vf* can be defined by means of function *VF\_open* e.g., as follows:

- (1) **VotingFarm\_t** \**vf*;
- (2) *vf* = *VF\_open*(5, *distance*);

After this statement has been executed, an object has been allocated, some initializations have occurred, and the address of the newly created object has been returned into *vf*. The number the user supplies as the argument of *VF\_open* is an integer which univokely represents the current voting farm and in fact distinguishes it from all other voting farms which possibly will be used at the same times—we may call it a VotingFarm-id. *distance* is an arbitrary metric i.e., a function which gets two pointers to opaque objects, computes a “distance”, and returns this value as a positive real number.

Each user module which needs to assemble the same voting farm should actually execute a *VF\_open* statement with the same number as an argument—it is the user’s responsibility to do like this. Likewise, coherent behaviour requires that the same metric function is referenced as second parameter of *VF\_open*.

*VF\_open* returns  $\Lambda$  in case of error; otherwise, it returns a pointer to a valid object.

⟨ Voting Farm Definition 6 ⟩ ≡

```

VotingFarm_t *VF_open(int vf_id, double (*distance)(void *, void *))
{
#ifdef STATIC
    static int vf_max_farms;
#endif

    AllocationClass
        VotingFarm_t *vf;
        static char *VFN = "VF_open";
    if (vf_id ≤ 0) {
        LogError(EC_ERROR, VFN,
            "Illegal_VotingFarm_Identifier_(%d)_---_should_be_greater_than_0.", vf_id);
        VF_error = E_VF_WRONG_VFID;
        return  $\Lambda$ ;
    }
#ifdef STATIC
    if ((vf = (VotingFarm_t *) malloc(sizeof(VotingFarm_t))) ≡  $\Lambda$ ) {
        LogError(EC_ERROR, VFN, "Memory_Allocation_Error.");
        VF_error = E_VF_CANT_ALLOC;
        return  $\Lambda$ ;
    }
#else
    /* if STATIC is defined, then we fetch the next entry from array 'Table' */
    if (vf_max_farms < VF_MAX_FARMS) vf = &Table[vf_max_farms++];
    else {
        LogError(EC_ERROR, VFN, "Too_many_farms.");
        VF_error = E_VF_TOO_MANY;
        return  $\Lambda$ ;
    }
#endif
    if (distance ≡  $\Lambda$ ) {
        LogError(EC_ERROR, VFN, "Invalid_Metric_Function_(NULL).");
        VF_error = E_VF_WRONG_DISTANCE;
        return  $\Lambda$ ;
    }

    vf→N = 0; /* zero the stack pointer */
    vf→vf_id = vf_id; /* record the vf id */

```

```
vf→distance = distance;    /* record the function pointer */  
vf→user_thread = vf→this_voter = -1;  
LocalLink(vf→pipe);    /* Create a means for communicating with the local voter */  
return vf;  
}
```

This code is used in section 1.

**7. Voting Farm Description.** Once a **VotingFarm\_t** pointer has been created and once an object has been correctly defined and attached to that pointer, the user needs to describe the farm: how many voters are needed, where they should be placed, how to refer to each voter, and so on. This is accomplished by means of function *VF\_add*. If the voting farm consists of  $N$  voters, then the user shall call *VF\_add*  $N$  times; each call describes a voter by attaching a couple  $(n, t)$  to it, where  $n$  is the node of the voter and  $t$  is its thread identifier. As an example, the following statements:

- (1) **VotingFarm\_t** \*vf;
- (2) vf = VF\_open(5, distance);
- (3) VF\_add(vf, 15, tid1);
- (4) VF\_add(vf, 21, tid2);
- (5) VF\_add(vf, 4, tid5);

declare (line (1)), define (line (2)), and describe (lines (3)–(5)) voting farm number 5. A triple of voters has been proposed; voter 0, identified by the couple  $(n, t) = (15, tid1)$ , voter 1, or couple  $(21, tid2)$ , and voter 2, or couple  $(4, tid5)$ .

Again it is the user's responsibility to operate in a coherent, consistent way during these phases: in this case, he or she needs to declare the farm in exactly the same order, with exactly the same cardinality, with the same attributes on all nodes. Exactly one node-id has to be present and equal to the number of the current node.

So far no thread has been launched, and no distributed action has taken place—therefore we talk of “passive voting farms” for farms that have been only declared, defined, and described, but not activated yet.

*VF\_add* returns a negative integer in case of error; otherwise, it returns zero.

⟨ Voting Farm Description 7 ⟩ ≡

```

int VF_add(VotingFarm_t *vf, int node, int identifier)
{
    static int this_node; /* set function name */
    static char *VFN = "VF_add";
    if (this_node ≡ 0) this_node = GET_ROOT()-ProcRoot-MyProcID;
    ⟨ Has vf been defined? 8 ⟩
    ⟨ Is vf a valid object? 9 ⟩
    vf->vf_node_stack[vf->N] = node;
    vf->vf_ident_stack[vf->N] = identifier;
    if (node ≡ this_node)
        if (vf->this_voter < 0) vf->this_voter = vf->N; /* store the current value of the stack pointer */
        else {
            LogError(EC_ERROR, VFN, "There_must_be_only_one_local_voter.");
            return VF_error = E_VF_TOO_MANY_LVOTERS;
        }
    vf->N++;
    ⟨ Check stacks growth 10 ⟩
    return VF_error = 0;
}

```

This code is used in section 1.

**8.** Checks if  $vf$  holds a valid (non- $\Lambda$ ) address.

```

⟨Has  $vf$  been defined? 8⟩ ≡
  if ( $vf \equiv \Lambda$ ) {
    LogError(EC_ERROR, VFN, "Undefined_VotingFarm_t_Object.");
    LogError(EC_ERROR, VFN, "\t(A_VF_open_is_probably_needed.)");
    return VF_error = E_VF_UNDEFINED_VF;
  }

```

This code is used in sections 7, 11, 24, and 30.

**9.** Checks if  $vf$  points to valid data.

```

⟨Is  $vf$  a valid object? 9⟩ ≡
  if ( $vf \rightarrow vf\_id < 0 \vee vf \rightarrow vf\_node\_stack \equiv \Lambda \vee vf \rightarrow vf\_ident\_stack \equiv \Lambda \vee vf \rightarrow N < 0$ ) {
    LogError(EC_ERROR, VFN, "Corrupted_or_Invalid_VotingFarm_t_Object.");
    return VF_error = E_VF_INVALID_VF;
  }

```

This code is used in sections 7 and 30.

**10.** Check if a stack overflow event has occurred.

```

⟨Check stacks growth 10⟩ ≡
  if ( $vf \rightarrow N \geq VF\_MAX\_NTS$ ) {
    LogError(EC_ERROR, VFN, "Stack_Overflow.");
    LogError(EC_ERROR, VFN, "\t(Increase_the_value_of_VF_MAX_NTS;_current_value_is_%d.",
      VF_MAX_NTS);
    return VF_error = E_VF_OVERFLOW;
  }

```

This code is used in section 7.

**11. Voting Farm Activation.** After having described a voting farm, next step is turning that passive description into a “living” (active) object: this is accomplished by means of function *VF\_run* which simply spawns the local voter and connects to it. Any inconsistency like e.g., zero or two local voters are managed at this point and results in specific error messages. The one argument **VotingFarm\_t** *\*vf* is passed to the newly created thread.

*VF\_run* returns a negative integer in case of error; otherwise, it returns zero.

⟨ Voting Farm Activation 11 ⟩ ≡

```

int VF_run(VotingFarm_t *vf){ AllocationClass
    int MyProcID;
    AllocationClass GlobId_t GlobId;
    AllocationClass
    int Error;
#ifdef SERVERNET
    extern LinkCB_t*link2server;
#endif    /* set function name */
    static char *VFN = "VF_run";

    ⟨ Has vf been defined? 8 ⟩
    ⟨ Has vf been described? 12 ⟩
    if (vf->this_voter < 0) {
        LogError(EC_ERROR, VFN, "No_voter_has_been_defined_to_be_local.");
        return E_VF_NO_LVOTER;
    }
    MyProcId = GET_ROOT()->ProcRoot->MyProcID;    /* Get the Global ID structure. */
    if (GetGlobId(&GlobId,  $\Lambda$ ) ≡ -1) {
        LogError(EC_ERROR, VFN, "Cannot_get_the_global_ID_of_the_thread.");
        return E_VF_GETGLOBID;
    }    /* for the time being, this field is treated as a flag which tells whether VF_run has been
        executed or not on voting farm vf. Its role will be different when FT_Create_Thread will be
        used instead of CreateThread. */
    vf->user_thread = 0;    /* first create a separate thread for the voter function */
#ifdef SERVERNET
    LogError(EC_MESS, VFN, "Creating_thread 'VF_voter()' via RTC_CreateLThread()");
    vf->rtc = RTC_CreateLThread (link2server, vf->vf_ident_stack[vf->this_voter], DIR_USER_TYPE,  $\Lambda$ ,
        0, (RTC_ptr_t) VF_voter, vf, sizeof ( LinkCB_t * ) );
    LogError(EC_MESS, VFN, "RTC_CreateLThread() has been executed.");
#else
    if (CreateThread( $\Lambda$ , 0, (int(*)()) VF_voter, &Error, vf) ≡  $\Lambda$ ) {
        LogError(EC_ERROR, VFN, "Cannot_start_a_voter_thread, error_code_%d.", Error);
        return VF_error = E_VF_CANT_SPAWN;
    }
#endif
    return VF_error = 0; }

```

This code is used in section 1.

**12.** This checks whether the farm has been described by means of at least one call to *VF\_add*.

$\langle \text{Has } vf \text{ been described? } 12 \rangle \equiv$

```

if (vf→N < 0) {
    LogError(EC_ERROR, VFN, "Voting_farm_%d_needs_to_be_described.", vf→vf_id);
    LogError(EC_ERROR, VFN, "\t(You_probably_need_to_execute_a_VF_add_statement.)");
    return VF_error = E_VF_UNDESCRIBED;
}

```

This code is used in sections 11 and 24.

**13.** This checks whether the farm has been activated by means of a previous call to function *VF\_run*.

$\langle \text{Has } vf \text{ been activated? } 13 \rangle \equiv$

```

if (vf→user_thread < 0) {
    LogError(EC_ERROR, VFN, "Voting_farm_%d_needs_to_be_activated.", vf→vf_id);
    LogError(EC_ERROR, VFN, "\t(You_probably_need_to_execute_a_VF_run_statement.)");
    return VF_error = E_VF_INACTIVE;
}

```

This code is used in section 24.

**14. Voting Farm Control.** All interactions between the user module and the farm go through the *VF\_control* and *VF\_control\_list* functions and objects of **VF\_msg\_t** type, aka messages.

```

⟨ Voting Farm Control 14 ⟩ ≡
  ⟨ Type VF_msg_t 15 ⟩
  ⟨ Build a VF_msg_t message 17 ⟩
  ⟨ Function VF_control_list 24 ⟩
  ⟨ Function VF_control 26 ⟩
  ⟨ Function VF_send 25 ⟩

```

This code is used in section 1.

**15.** A message is an object which holds the information needed for a user module to request a service to a voter and for a voter to respond to a previous user's request. Its definition is simple:

```

⟨ Type VF_msg_t 15 ⟩ ≡
  typedef struct {
    int code;
    void *msg;
    int msglen;
  } VF_msg_t;

```

This code is used in section 14.

**16.** The *code* field specifies the nature of the message (see table (see [table1]) for a complete reference); depending on this, some data may be pointed to by the opaque pointer *msg*. In this case, *msglen* represents the size of that data. This is an example of its usage:

- (1) **VF\_msg\_t** *message*;
- (2) *message.code* = VF\_INP\_MSG;
- (3) *message.msg* = *strdup(input)*;
- (4) *message.msglen* = 1 + *strlen(input)*;

Note that the voter thread assumes that the user module allocates new memory for each new *message.msg* that is sent to it i.e., it won't make a personal copy of the area; on the contrary, it will simply store the pointer and use the pointed storage. Moreover, also deallocation of objects previously defined by the user module will be considered to be managed by this latter.

**17.** These functions hide the **VF\_msg\_t** structure to the user.

```

⟨ Build a VF_msg_t message 17 ⟩ ≡
  ⟨ Input message setup 18 ⟩
  ⟨ Scaling factor message setup 19 ⟩
  ⟨ Message to choose the algorithm 20 ⟩

```

This code is used in section 14.



**18.** Build up an **VF\_msg\_t** object holding a **VF\_INP\_MSG** message.

⟨Input message setup 18⟩ ≡

```
VF_msg_t *VFO_Set_Input_Message(void *obj, size_t siz)
{
    static VF_msg_t m;
    if (obj ≡ Λ) {
        VF_error = E_VF_NULLPTR;
        return Λ;
    }
    m.code = VF_INP_MSG;
    m.msg = obj;
    m.msglen = siz;
    return &m;
}
```

This code is used in section 17.

**19.** Build up an **VF\_msg\_t** object holding a **VF\_SCALING** message.

⟨Scaling factor message setup 19⟩ ≡

```
VF_msg_t *VFO_Set_Scaling_Factor(double *sf)
{
    static VF_msg_t m;
    m.code = VF_SCALING_FACTOR;
    m.msg = sf;
    m.msglen = sizeof(double);
    return &m;
}
```

This code is used in section 17.

**20.** Build up an **VF\_msg\_t** object holding the chosen algorithm.

⟨Message to choose the algorithm 20⟩ ≡

```
VF_msg_t *VFO_Set_Algorithm(int algorithm)
{
    static VF_msg_t m;
    m.code = VF_SELECT_ALG;
    m.msglen = algorithm;
    return &m;
}
```

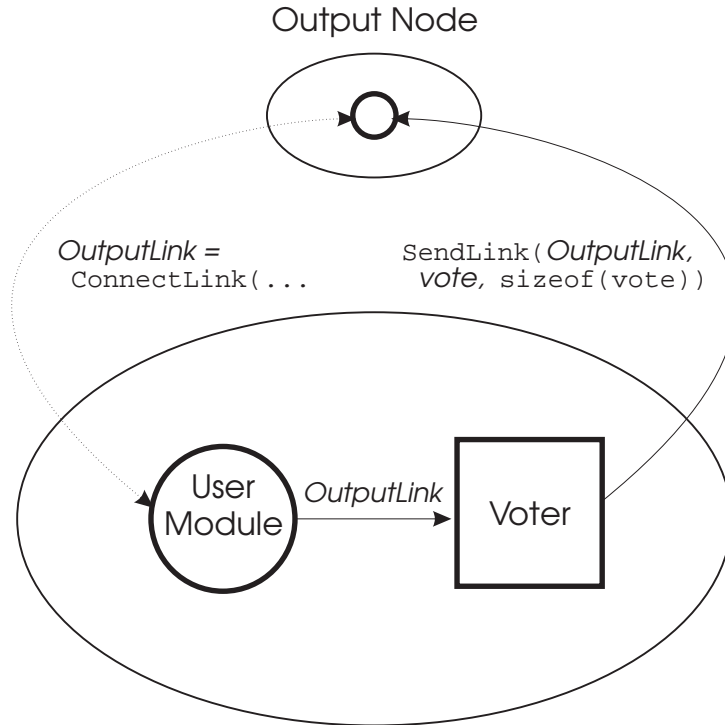
This code is used in section 17.

**21.** Function *VF\_control\_list* accepts an array of messages that are transferred across the communication network as one buffer.

Function *VF\_control\_list* and *VF\_control* return a negative integer in case of error; otherwise, they return zero.

**22.** List of possible message codes going: from the user module to its local voter (represented as  $\mathcal{U} \rightarrow \mathcal{L}$ ), and vice-versa (represented as  $\mathcal{U} \rightarrow \mathcal{L}$ ):

- **VF\_INP\_MSG**: a *msglen*-byte-long input message is stored at the address referenced by the opaque pointer *msg* ( $\mathcal{U} \rightarrow \mathcal{L}$ ).
- **VF\_OUT\_LCB**: the information pointed to by *msg* is the link control block for connecting the local voter to the output module ( $\mathcal{U} \rightarrow \mathcal{L}$ ); see Figure 3.
- **VF\_SELECT\_ALG**: *msg* points to a code which identifies a particular majority voting algorithm out of the set of available algorithms ( $\mathcal{U} \rightarrow \mathcal{L}$ ).
- **VF\_DESTROY**: a signal meaning that the receiving voter should terminate itself after having freed all no more needed memory ( $\mathcal{U} \rightarrow \mathcal{L}$ ).
- **VF\_NOP**: No Operation, something like an **ImAlive** signal. For the time being this event is not used.
- **VF\_RESET**: on the arrival of this signal the status is set so to be able to perform a new voting session with the current farm ( $\mathcal{U} \rightarrow \mathcal{L}$ ).
- **VF\_REFUSED**: certain operations may be refused; for example, if one tries to execute a *VF\_close()* before a broadcasting operation has been completed, then the voter returns this message to its user module ( $\mathcal{L} \rightarrow \mathcal{U}$ ).
- **VF\_QUIT**: before quitting, the voter generates a **VF\_QUIT** event ( $\mathcal{L} \rightarrow \mathcal{U}$ ).
- **VF\_DONE**: after broadcasting, a **VF\_DONE** event is raised ( $\mathcal{L} \rightarrow \mathcal{U}$ ).
- **VF\_EPSILON**: An  $\epsilon$  threshold value needed by the formalized majority voting algorithm ( $\mathcal{U} \rightarrow \mathcal{L}$ ).
- **VF\_ERROR**: A generic error has occurred ( $\mathcal{L} \rightarrow \mathcal{U}$ ).
- **VF\_SCALING\_FACTOR**: used in the Weighted Averaging Technique (see below) ( $\mathcal{U} \rightarrow \mathcal{L}$ ).



**Figure 3.** The user module connects to an output module (dashed curve) and then sends to its local voter a **VF\_OUT\_LCB** message holding the relevant link control. As soon as the voter has performed its voting task, it sends its vote to the output module by means of that link control block.

```
#define VF_INP_MSG 100
#define VF_OUT_LCB 101
#define VF_SELECT_ALG 102
#define VF_DESTROY 103
#define VF_NOP 104
```

```
#define VF_RESET 105
#define VF_REFUSED 106
#define VF_QUIT 107
#define VF_DONE 108
#define VF_EPSILON 109
#define VF_ERROR 110
#define VF_SCALING_FACTOR 111
```

**23.** List of possible message codes going from the local voter to its fellows and vice-versa. They have the same meaning of those defined in the previous section e.g., `VF_V_INP_MSG` is an input message coming from a fellow voter.

```
#define VF_V_INP_MSG 200
#define VF_V_DESTROY 203
#define VF_V_NOP 204
#define VF_V_RESET 205
#define VF_V_ERROR 210
```

**24.** This function sends one or more messages to the local voter of voting farm *vf*:

⟨Function *VF\_control\_list* 24⟩ ≡

```

int VF_control_list(VotingFarm_t *vf, VF_msg_t *msg, int n)
{
    AllocationClass
    int rv; /* set function name */
    static char *VFN = "VF_control_list";
#ifdef VFDEBUG
    LogError(EC_MESS, VFN, "within_control_list");
#endif /* VFDEBUG */
    ⟨Has vf been defined? 8⟩
    ⟨Has vf been described? 12⟩
    ⟨Has vf been activated? 13⟩
#ifdef VFDEBUG
    LogError(EC_MESS, VFN, "checked: defined, described, and activated");
#endif /* VFDEBUG */
    if (n < 1 ∨ n > VF_MAX_MSGS) { /* doubt: should it be an error or a warning? */
        LogError(EC_ERROR, VFN, "Wrong_message_number_(%d) --- should be between 1 and %d.\n",
            n, VF_MAX_MSGS);
        return E_VF_WRONG_MSG_NB;
    }
    if (vf->pipe[0] ≠ Λ) {
#ifdef VFDEBUG
        LogError(EC_MESS, VFN, "Next_statement_is_SendLink(%x, %x, %d)", vf->pipe[0], &msg[0],
            n * sizeof (msg[0]));
#endif /* VFDEBUG */
        rv = SendLink(vf->pipe[0], &msg[0], n * sizeof (msg[0]));
        if (rv ≠ n * sizeof (msg[0])) {
            LogError(EC_ERROR, VFN, "Cannot_send_the_message_to_local_voter.");
            return E_VF_SENDLINK;
        }
    }
#ifdef VFDEBUG
    LogError(EC_MESS, VFN, "exiting...");
#endif /* VFDEBUG */
    return VF_error = 0;
}
LogError(EC_ERROR, VFN, "Corrupted_or_Invalid_VotingFarm_t_Object.");
return VF_error = E_VF_INVALID_VF;
}

```

This code is used in section 14.

**25.** To be described...

```

⟨Function VF_send 25⟩ ≡
#define VF_MAXARGS 31
void VF_send(VotingFarm_t *vf, int argc, ...)
{
    AllocationClass
    va_list ap;
    AllocationClass
    VF_msg_t array[VF_MAXARGS];
    AllocationClass
    VF_msg_t *mp;
    AllocationClass
    int i;
    if (argc > VF_MAXARGS) argc = VF_MAXARGS;
    va_start(ap, argc);
    for (i = 0; i < argc; i++) {
        mp = va_arg(ap, VF_msg_t *);
        memcpy(array + i, mp, sizeof(VF_msg_t));
    }
    va_end(ap);
    VF_control_list(vf, array, argc);
}

```

This code is used in section 14.

**26.** Simply a shortcut.

```

⟨Function VF_control 26⟩ ≡
int VF_control(VotingFarm_t *vf, VF_msg_t *msg)
{
    return VF_control_list(vf, msg, 1);
}

```

This code is used in section 14.

**27.** Voting Farm Destruction. This is another simple shortcut for sending the VF\_DESTROY message to a voting farm.

```

⟨Voting Farm Destruction 27⟩ ≡
int VF_close(VotingFarm_t *vf)
{
    AllocationClass
    VF_msg_t msg;
    AllocationClass
    int r;
    msg.code = VF_DESTROY;
    r = VF_control(vf, &msg);
    return r;
}

```

This code is used in section 1.

28. to be described.

```

< Voting Farm Read 28 > ≡
VF_msg_t *VF_get(VotingFarm_t *vf)
{
    static VF_msg_t msg;
    AllocationClass
    int recv, n;
    AllocationClass Option_to[5];    /* used to be Option_to[2] */
    static char *VFN = "VF_get";
#ifdef VFDEBUG
    LogError(EC_MESS, VFN, "\t\tvf==%x, \t\tvf->pipe==%x, \t\tvf->pipe[0]==%x, \t\tvf->pipe[1]==%x", vf,
        vf->pipe, vf->pipe[0], vf->pipe[1]);
#endif    /* VFDEBUG */
    o[0] = ReceiveOption(vf->pipe[0]);
    o[1] = TimeAfterOption(TimeNow() + VF_EVENT_TIMEOUT * CLOCK_TICK);
    switch ((n = SelectList(2, o)) {
case 1: LogError(EC_ERROR, VFN, "Timeout_\t\tcondition_\t\treached.");
        LogError(EC_ERROR, VFN,
            "\t\t(Maybe\t\tVF_EVENT_TIMEOUT_\t\tshould_\t\tbe_\t\tenlarged?\t\tNow\t\tit's\t\t%d\t\tseconds.)",
            VF_EVENT_TIMEOUT);
        msg.code = VF_ERROR;
        msg.msglen = VF_error = E_VF_EVENT_TIMEOUT;
        return &msg;
case 0:
        if ((recv = RecvLink(vf->pipe[0], (void *) &msg, sizeof (msg))) ≤ 0) {
            LogError(EC_ERROR, VFN, "Can't\t\tRecvLink\t\t[A\t\tmessage\t\tfrom\t\tthe\t\tlocal\t\tvoter]");
            LogError(EC_ERROR, VFN, "\t\t(return\t\tcode\t\tis\t\t%d.)", recv);
            msg.code = VF_ERROR;
            msg.msglen = VF_error = E_VF_RECVLINK;
            return &msg;
        }
        break;
default: LogError(EC_ERROR, VFN, "Can't\t\tSelect\t\t---\t\tretvalue\t\tis\t\t%d", n);
        msg.code = VF_ERROR;
        msg.msglen = VF_error = E_VF_SELECT;
        return &msg;
    }    /* end switch */
#ifdef VFDEBUG
    LogError(EC_MESS, VFN, "Received\t\ta\t\tmessage\t\t(%d\t\tbytes)\t\tfrom\t\tthe\t\tvoter.", recv);
#endif    /* VFDEBUG */
    return &msg;
}

static int voter_sendcode(LinkCB_t * UserLink, int code)
{
    AllocationClass
    int rv;
    AllocationClass
    VF_msg_t msg;
    static char *VFN = "voter_sendcode";
    msg.code = code;

```

```

    rv = SendLink(UserLink, &msg, sizeof (msg));
    if (rv ≠ sizeof (msg)) {
        LogError(EC_ERROR, VFN, "Cannot_send_the_message_to_the_user_module.");
        return E_VF_SENDLINK;
    }
    return rv;
}
static int voter_sendmsg(LinkCB_t * UserLink, VF_msg_t *msg)
{
    AllocationClass
        int rv;
        static char *VFN = "voter_sendmsg"; /* static function ⇒ VFN is not touched */
    rv = SendLink(UserLink, msg, sizeof (*msg));
    if (rv ≠ sizeof (*msg)) {
        LogError(EC_ERROR, VFN, "Cannot_send_the_message_to_the_user_module.");
        return E_VF_SENDLINK;
    }
    return rv;
}

```

This code is used in section 1.

**29.** Voting functions are stored into the *DoVoting* array.

⟨Voting Algorithms 29⟩ ≡

```

typedef struct {
    unsigned char *vote;
    int outcome;
} vote_t;
⟨Voting Functions 52⟩
typedef void (*voter_t)(VotingFarm_t *, void *[], int, vote_t *);
static voter_t DoVoting[VF_NB_ALGS] = { VFA_ExactConcensus,
    VFA_MajorityVoting,
    VFA_MedianVoting,
    VFA_PluralityVoting,
    VFA_WeightedAveraging,
    VFA_SimpleMajorityVoting,
    VFA_SimpleAverage,
};

```

This code is used in section 1.

**30. The Voter Function.** The function at the basis of the voting thread.

```

⟨ The Voter Function 30 ⟩ ≡
  static int VF_voter(VotingFarm_t *vf)
  {
    LinkCB_t * UserLink, *OutputLink, **links;
#ifdef SERVERNET
    LinkCB_t * serverlink = ConnectServer();
#endif /* SERVERNET */
    Option_t * options;
    int this_voter, this_node, N, i, opt, input_nr;
    VF_msg_t msg[VF_MAX_MSGS];
    int msgnum;
    VF_msg_t done;
    int Algorithm = VFA_MAJORITY;
    char buffer[VF_MAX_INPUT_MSG + sizeof(int)];
    int Error, recv;
    int input_length;
    void **voter_inputs;
    unsigned char *vote = st_VFA_vote;
    vote_t rvote;
    unsigned int t0, tn; /* set function name */
    static char *VFN = "VF_voter";

    t0 = TimeNow();
#ifdef SERVERNET
    Set_Phase(serverlink, VFP_INITIALISING);
#endif
    input_nr = input_length = 0;
    UserLink = OutputLink = Λ;
    vf-broadcast-done = vf-inp-msg-got = vf-destroy-requested = NO;
    rvote.vote = vote;

    ⟨ Has vf been defined? 8 ⟩
    ⟨ Is vf a valid object? 9 ⟩

    this_voter = vf-this_voter;
    this_node = vf-vf_node_stack[this_voter];
    if (GET_ROOT()-ProcRoot-MyProcID ≠ this_node) {
      LogError(EC_ERROR, VFN, "Corrupted_or_Invalid_VotingFarm_t_Object.");
      return VF_error = E_VF_INVALID_VF;
    }
    N = vf-N; /* Connect to the local Agent */
#ifdef SERVERNET
    ⟨ Ask the Server to set up a connection to an Agent 61 ⟩
#endif /* SERVERNET */
    /* Get the ( LinkCB_t * ) for communicating with the user module */
    UserLink = vf-pipe[1];

    ⟨ Create a cliqué 32 ⟩
    ⟨ Poll the user link, the farm links, and the server link 37 ⟩
  }
  ⟨ An example of metric function 31 ⟩

```

This code is used in section 1.



**31.** An example of metric function: a double-returning version of *strcmp*.

```

< An example of metric function 31 > ≡
    double dstrcmp(void *a, void *b)
    {
        return (double) strcmp(a, b);
    }

```

This code is used in section 30.

**32.** A cliqué (fully interconnected crossbar) is set up among the voters. This is done in two “flavours:” in the **STATIC** one we make use of predefined static data, otherwise we perform *malloc()*’s.

```

< Create a cliqué 32 > ≡
#ifndef STATIC
    < Allocate an array of LinkCB_t pointers 33 >
#else
    < Initialize an array of LinkCB_t pointers 34 >
#endif /* STATIC */
    < Connect to your N-1 fellows 35 >

```

This code is used in section 30.

**33.** An array of Link Control Block Pointers is needed in order to realize the cliqué.

```

< Allocate an array of LinkCB_t pointers 33 > ≡
    links = ( LinkCB_t * ) malloc ( N * sizeof ( LinkCB_t * ) ); options = ( Option_t * )
        malloc((N + 1) * sizeof (Option_t));
    voter_inputs = (void **) calloc(N, sizeof(void *));
    if (links ≡ Λ ∨ options ≡ Λ ∨ voter_inputs ≡ Λ) {
        LogError(EC_ERROR, VFN, "Memory_Allocation_Error.");
        return VF_error = E_VF_CANT_ALLOC;
    }

```

This code is used in section 32.

**34.** This section is supplied in case the user is willing to use the *static* version of this tool. Rather than allocating memory, we link statically-allocated memory to the appropriate pointers and we initialize them—where needed.

```

< Initialize an array of LinkCB_t pointers 34 > ≡
    links = st_links;
    options = st_options;
    voter_inputs = st_voter_inputs;
    memset(voter_inputs, 0, VF_STATIC_MAX_INP_MSG);

```

This code is used in section 32.

**35.** “By the implementation of queues the calling order {to *ConnectLink*} does not matter.” [11]. As a consequence, a simple **for** should suffice to create the farm.

$N+1$  options are “received”:  $N-1$  for the cliqué set-up, 1 for connecting to the user module, 1 for connecting to the server; more precisely:

- *options*[*this\_voter*] regards the user module;
- *options*[ $N$ ] regards the local server;
- the rest regards the fellow voters.

⟨ Connect to your  $N-1$  fellows 35 ⟩  $\equiv$

```
#ifndef SERVERNET
    Set_Phase(serverlink, VFP_CONNECTING);
#endif
for (i = 0; i < N; i++) {
    if (i ≠ this_voter) {
        links[i] = ConnectLink(vf→vf_node_stack[i], VF_RequestId(vf→vf_id, i, this_voter), &Error);
        options[i] = ReceiveOption(links[i]);
        if (links[i] ≡ Λ) {
            LogError(EC_ERROR, VFN, "Cannot_connect_to_voter_%d.", i);
            return VF_error = E_VF_CANT_CONNECT;
        }
    }
    else {
        options[i] = ReceiveOption(UserLink);
    }
}
#endif SERVERNET
options[N] = ReceiveOption(serverlink);
#endif /* SERVERNET */
```

This code is used in section 32.

**36.** This function creates a new request id beginning from voting farm id *vf<sub>n</sub>* and voter id’s *v* and *w*.

```
static int VF_RequestId(int vfn, int v, int w)
{
    AllocationClass
        int a, b;
        static int hundreds = VF_MAX_ANTS * VF_MAX_ANTS;
        if (v > w) a = w, b = v;
        else a = v, b = w;
        return hundreds * (vfn + 1) + a * VF_MAX_ANTS + b;
}
```

**37.** If control reaches this section it means that the cliqué has been successfully established between the voters. All future actions depend on the control and input messages of the user; therefore, the voter puts itself into an “endless” loop waiting for new messages to arrive and to be managed. This event-driven loop indeed resembles the one that may be found in any X11 client to manage interactions with the keyboard, the pointer, the display server, and so on.

```

⟨ Poll the user link, the farm links, and the server link 37 ⟩ ≡    /* t0 = TimeNow(); */
    while (1)
    {
#ifdef SERVERNET
        opt = SelectList(N + 1, options);
#else
        opt = SelectList(N, options);
#endif    /* SERVERNET */
        ⟨ A message from the user module 38 ⟩
        else ⟨ A message from the cliqué 43 ⟩
#ifdef SERVERNET
        else ⟨ A message from the server module 46 ⟩
#endif    /* SERVERNET */
        else {
            LogError(EC_ERROR, VFN, "Unknown_sender\n");
            return VF_error = E_VF_UNKNOWN_SENDER;
        }
        if (input_nr ≡ N ∧ vf→broadcast_done ≡ YES ∧ once) {
            FILE *f;
            char fname[80];
            tn = TimeNow();
#ifdef TIMESTATS
            sprintf(fname, "overhead.%d", this_voter);
            f = fopen(fname, "a+");
            fprintf(f, "%u_%u_%lf\n", t0, tn, (double)(tn - t0)/CLOCK_TICK);
            fclose(f);
#endif
            once = 0;
        }
    }
}

```

This code is used in section 30.

**38.** If the received options is option # *this\_voter*, then a message is coming from the user module.

⟨ A message from the user module 38 ⟩ ≡

```

if (opt ≡ this_voter) {      /* Receives the data and checks whether it is an integral multiple of the
    message size or not. In that latter case, an error is issued. */
    if ((msgnum = RecvLink(UserLink, msg, VF_MAX_MSGS * sizeof (*msg))) % sizeof (*msg)) {
        LogError(EC_ERROR, VFN, "Can't RecvLink[A_message_from_the_user_module]");
        LogError(EC_ERROR, VFN, "size_of_the_message_is_%d, sizeof(*msg)is_%d, (1)%(2)is_%d",
            msgnum, sizeof (*msg), msgnum % sizeof (*msg));
        return VF_error = E_VF_RECVLINK;
    }
    msgnum /= sizeof (*msg);
#ifdef VFDEBUG
    LogError(EC_MESS, VFN, "<voter_%d>Received_a_msg_from_the_user_module", this_node);
    LogError(EC_MESS, VFN, "(code==%d).msgnum==%d.StartingUsermsgmanagement\n",
        msg[0].code, msgnum);
#endif
    {
        int i;
        ⟨ User message management 39 ⟩
    }
}

```

This code is used in section 37.

**39.** A message from the user has been received. Deal with that message. (Note that messages are buffered into the *msg[]* array.)

```

⟨ User message management 39 ⟩ ≡
    for (i = 0; i < msgnum; i++) { void *memdup(void *, size_t);
#ifdef VFDEBUG
        LogError(EC_MESS, VFN, "<voter_<math>id</math>>: User_message_management: loop_<math>d</math>, code==<math>d</math>\n",
            this_voter, i, msg[i].code);
#endif
        switch (msg[i].code) {
case VF_INP_MSG:
#ifdef VFDEBUG
            LogError(EC_MESS, VFN, "<voter_<math>id</math>> VF_INP_MSG received.\n", this_node);
#endif
            voter_inputs[this_voter] = memdup(msg[i].msg, msg[i].msglen);
            input_length = msg[i].msglen;
            input_nr++; /* t0 = TimeNow(); */
#ifdef VFDEBUG
            printf("<voter_<math>id</math>> message_<math>(as\_a\_double)</math> is_<math>lf</math>.\n", this_node, *((double *) msg[i].msg));
#endif
            ⟨ Check for a complete message suite; if so, vote, and possibly deliver the outcome 48 ⟩
            vf_inp_msg_got = YES;
            if (this_voter ≡ input_nr - 1) {
                int j;
                ⟨ Broadcast the Input Message 40 ⟩
                vf_broadcast_done = YES;
            }
            break;
            ⟨ case VF_DESTROY: 41 ⟩ /* break; unneeded, because the statement is unreachable */
            ⟨ case VF_OUT_LCB: 42 ⟩ break;
case VF_SELECT_ALG: Algorithm = msg[i].msglen;
            break;
case VF_SCALING_FACTOR: ScalingFactor = *((double *) msg[i].msg);
            break;
case VF_EPSILON:  $\epsilon$  = *((double *) msg[i].msg);
            break;
case VF_RESET: input_nr = input_length = 0;
            OutputLink =  $\Lambda$ , rvote.outcome = *vote = '\0';
            vf_broadcast_done = vf_inp_msg_got = vf_destroy_requested = NO;
#ifdef STATIC
            {
                AllocationClass
                int i;
                for (i = 0; i < vf-N; i++) {
                    free(voter_inputs[i]);
                    voter_inputs[i] =  $\Lambda$ ;
                }
            }
#endif
            break;

```

```

case VF_NOP:    /* for the time being, nothing */
    break;
default: printf("<voter_<_<_default_<_case_<_in_<_switch_<_code==<_d\\n", this_voter, msg[i].code);
    break; }    /* end switch */
}              /* end for */

```

This code is used in section 38.

40. The actual transmission of this voter's input message to all other voters in the farm. The buffer is built up so to tie the code of the message and the message itself.

```

<Broadcast the Input Message 40> ≡
    *((int *) buffer) = VF_V_INP_MSG;
    memcpy(buffer + sizeof(int), voter_inputs[this_voter], input_length);
#ifdef SERVERNET
    Set_Phase(serverlink, VFP_BROADCASTING);
#endif
#ifdef ZEROPERM
    for (j = 0; j < N; j++) {
        if (j ≠ this_voter) {
#ifdef VFDEBUG
            LogError(EC_MESS, VFN, "<voter_<_<_broadcasting_<_(j==<_d)\\n", this_voter, j);
#endif
            if (input_length + sizeof(int) ≠ SendLink(links[j], buffer, input_length + sizeof(int))) {
                LogError(EC_ERROR, VFN, "Cannot_<_SendLink_<_to_<_voter_<_d.", j);
                return VF_error = E_VF_SENDLINK;
            }
        }
    }
}
#else
    for (j = this_voter + 1; j < N; j++) {
        if (input_length + sizeof(int) ≠ SendLink(links[j], buffer, input_length + sizeof(int))) {
            LogError(EC_ERROR, VFN, "Cannot_<_SendLink_<_to_<_voter_<_d.", j);
            return VF_error = E_VF_SENDLINK;
        }
    }
    for (j = 0; j < this_voter; j++) {
        if (input_length + sizeof(int) ≠ SendLink(links[j], buffer, input_length + sizeof(int))) {
            LogError(EC_ERROR, VFN, "Cannot_<_SendLink_<_to_<_voter_<_d.", j);
            return VF_error = E_VF_SENDLINK;
        }
    }
}
#endif

```

This code is used in sections 39 and 45.

**41.** Management of a user message of type VF\_DESTROY.

```

⟨ case VF_DESTROY: 41 ⟩ ≡
  case VF_DESTROY: /* ¡Broadcast a VF_V_DESTROY event! ?? */
  if (vf→broadcast_done ≡ NO ∧ vf→N ≠ 1) {
    voter_sendcode( UserLink, VF_REFUSED);
    break;
  }
  else {
#ifdef SERVERNET
    Set_Phase( serverlink, VFP_QUITTING);
#endif
    voter_sendcode( UserLink, VF_QUIT);
#ifdef SERVERNET
    { int myident = vf→vf_ident_stack[this_voter]; int error ;
    #ifdef DoBreakServer
      if ( ( error = BreakServer( serverlink ) ) ≠ 0 ) LogError (EC_ERROR, VFN,
        "BreakServer_failed, error:%d", error ) ;
    #endif /* DoBreakServer */
    #ifdef VFDEBUG
      LogError(EC_MESS, VFN, "<voter_>_myident=%d. Bye.\n", myident, this_voter);
    #endif
    }
    #endif /* SERVERNET */
    exit(0);
    return VF_error = 0; }

```

This code is used in section 39.

**42.** Management of a user message of type VF\_OUT\_LCB.

```

⟨ case VF_OUT_LCB: 42 ⟩ ≡
  case VF_OUT_LCB: OutputLink = ( LinkCB_t * ) msg[i].msg;
  if (OutputLink ≠ Λ) {
    if (rvote.outcome ≡ VF_SUCCESS) {
      ⟨ Deliver the Outcome 50 ⟩
    }
  }
  else {
    LogError(EC_ERROR, VFN, "Invalid_output_link_control_block_ can't deliver.");
  } /* In the event of a VF_DESTROY message, the local voter should inform its fellow via the
    broadcasting of a VF_V_DESTROY event. ¡Broadcast a VF_V_DESTROY event! = */

```

This code is used in section 39.

**43.** If the received options is not option #  $N$  nor option #  $this\_voter$ , then a message is coming from a voter in the farm. Note that this time messages cannot be buffered—only one message at a time will be received. Moreover, messages come from a different memory space—for this reason, the structure of the message can't be that of a **VF\_msg\_t** object. A different approach must be used: an integer representing the code message should be directly attached to an opaque area. The resulting buffer constitutes the message.

⟨ A message from the cliqué 43 ⟩ ≡

```

if ( $opt \neq this\_voter \wedge opt \neq N$ ) {
  if ( $(recv = RecvLink(links[opt], buffer, VF\_MAX\_INPUT\_MSG)) < 0$ ) {
    LogError(EC_ERROR, VFN, "Can't RecvLink[A_message_from_the_clique]");
    LogError(EC_ERROR, VFN, "\t(Sender_is_voter%d, size_of_message_is%d.)", opt, recv);
    return VF_error = E_VF_RECVLINK;
  }
  msg[0].code = *((int *) buffer);
  msg[0].msg = buffer + sizeof(int);
  msg[0].msglen = recv - sizeof(int);
  ⟨ Cliqué message management 44 ⟩
}

```

This code is used in section 37.



44. A new message has come from a voter in the cliqué.

⟨ Cliqué message management 44 ⟩ ≡

```

    switch (msg[0].code) {
    case VF_V_INP_MSG:
#ifdef VFDEBUG
        printf("voter_%d_received_the_input_message_from_voter_%d:_%lf\n", this_voter, opt, *((double
            *) msg[0].msg));
#endif
        if (input_length == 0) input_length = msg[0].msglen;
        else {
            if (input_length != msg[0].msglen) {
                LogError(EC_ERROR, VFN, "Wrong_input_size");
                return VF_error = E_VF_INPUT_SIZE;
            }
        }
#ifdef STATIC
        if ((voter_inputs[opt] = (void *) malloc(input_length)) == 0) {
            LogError(EC_ERROR, VFN, "Memory_Allocation_Error.");
            return VF_error = E_VF_CANT_ALLOC;
        }
#else
        voter_inputs[opt] = (void *) &st_voter_inputs_data[opt][0];
#endif
        memcpy(voter_inputs[opt], msg[0].msg, input_length);
        input_nr++;
        ⟨ Check for a complete message suite; if so, vote, and possibly deliver the outcome 48 ⟩
        ⟨ Check if it's your turn to broadcast; if so, do it, and take note of that 45 ⟩
        break;
    case VF_V_DESTROY:    /* Is there a use for such a message? */    /* for the time being, no action */
#ifdef VFDEBUG
        LogError(EC_MESS, VFN, "voter_%d_received_a_VF_V_DESTROY_message_from_voter_%d\n",
            this_voter, opt);
#endif
        break;
    case VF_V_ERROR:      /* The voter notifies an error condition */    /* for the time being, no action */
        break;
    case VF_V_RESET:      /* Is there a use for such a message? */    /* for the time being, no action */
        break;
    case VF_V_NOP:        /* for the time being, no action */
        break;
    }    /* end switch */

```

This code is used in section 43.

**45.** Broadcasting is performed in an ordered fashion so to prevent deadlocks—a voter is allowed to broadcast only when the following two conditions hold at once:

- it has not performed a broadcast before, and
- the vote-id (a number from 0 to  $vf \rightarrow N - 1$ ) is less than or equal to the current number of input messages that have been received (user message included), minus one.

⟨ Check if it's your turn to broadcast; if so, do it, and take note of that 45 ⟩  $\equiv$

```
/* if (this_voter != input_nr - 1) */
if (this_voter == input_nr - 1) {
    if (vf_inp_msg_got == YES ^ vf_broadcast_done == NO) {
        int j;
        ⟨ Broadcast the Input Message 40 ⟩
        vf_broadcast_done = YES;
    }
}
```

This code is used in section 44.

**46.** If the received options is option #  $N$ , then a message is coming from the local server module.

⟨ A message from the server module 46 ⟩  $\equiv$

```
if (opt == N) {
    int recv;
    char msg[FTB_ELEMENT_SIZE];
    if ((recv = RecvLink(serverlink, (void *) msg, FTB_ELEMENT_SIZE)) <= 0)
        LogError(EC_ERROR, VFN, "couldn't receive a message from the server\n");
    else LogError(EC_DEBUG, VFN, "got server message of %d bytes.\n", recv);
    ⟨ Server message management 47 ⟩
}
```

This code is used in section 37.

**47.** So far, an empty section.

⟨ Server message management 47 ⟩  $\equiv$  /\* should deal with message kept in msg[], size recv. \*/

This code is used in section 46.

**48.** Every time a new message has come and consequently  $input\_nr$  has been incremented, we must check if it's time for voting and if so, after voting, we check if we have an output address

⟨ Check for a complete message suite; if so, vote, and possibly deliver the outcome 48 ⟩  $\equiv$

```
#ifndef VFDEBUG
    LogError(EC_MESS, VFN, "<voter %d> input_nr == %d, N == %d\n", this_voter, input_nr, N);
#endif
if (input_nr == N) {
    ⟨ Perform Voting 49 ⟩
    if (OutputLink != Λ) {
        ⟨ Deliver the Outcome 50 ⟩
    } /* input_nr = 0; */
}
```

This code is used in sections 39 and 44.

**49.** The actual voting algorithm is managed by a function whose address is kept in the *DoVoting* array at entry no. *Algorithm*.

```

⟨Perform Voting 49⟩ ≡
  if (Algorithm ≥ 0 ∧ Algorithm < VF_NB_ALGS) {
#ifdef SERVERNET
    Set_Phase(serverlink, VFP_VOTING);
#endif
    DoVoting[Algorithm](vf, (void **) voter_inputs, input_length, &rvote);
  }
  else {
    LogError(EC_ERROR, VFN, "Wrong_Algorithm_number: %d, not in [0, %d[", Algorithm, VF_NB_ALGS);
    return VF_error = E_VF_WRONG_ALGID;
  }
#ifdef VFDEBUG
  if (rvote.outcome ≡ VF_SUCCESS) {
    LogError(EC_MESS, VFN, "<voter %d> is sending a VF_DONE msg to the user --- vote == %lf.\n",
      this_voter, *(double *) rvote.vote);
    printf("vote == %lf\n", *(double *) rvote.vote);
  }
  else LogError(EC_MESS, VFN, "Vote is undefined.");
#endif
  done.code = VF_DONE; /* possibly Λ, which means: "no unique vote is available" */
  done.msglen = rvote.outcome;
  done.msg = rvote.vote;
  recv = voter_sendmsg(UserLink, &done);
#ifdef VFDEBUG
  LogError(EC_MESS, VFN, "<voter %d> sent a VF_DONE msg (%d bytes) to the user.\n", this_voter,
    recv);
#endif

```

This code is used in section 48.

**50.** The vote is sent to the output module.

```

⟨ Deliver the Outcome 50 ⟩ ≡
  if (rvote.outcome ≡ VF_SUCCESS) {
    if (input_length ≠ SendLink(OutputLink, vote, input_length)) {
      LogError(EC_ERROR, VFN, "Cannot_deliver_the_output.");
      return VF_error = E_VF_DELIVER;
    }
#ifdef SERVERNET
    Set_Phase(serverlink, VFP_WAITING);
#endif
  }
  else {
    char c = 0;
    if (SendLink(OutputLink, &c, 1) ≠ 1) {
      LogError(EC_ERROR, VFN, "Cannot_deliver_the_negative_result.");
      return VF_error = E_VF_DELIVER;
    }
#ifdef SERVERNET
    Set_Phase(serverlink, VFP_FAILED);
#endif
  }

```

This code is used in sections 42 and 48.

**51.** *VF\_error*: the *perror* function of the VotingFarm class. Statically defined as a vector of strings, its entries can be addressed as “*e*”, where *e* is the error condition returned in *VF\_error*. The number of messages has been specified so to reduce the risk of inconsistencies.

⟨ Voting Farm Error Function 51 ⟩ ≡

```
static char *errors[VF_ERROR_NB] = {"no_error", /* no error */
  "An_internal_stack_has_reached_its_upper_limit", /* E_VF_OVERFLOW */
  "The_system_was_not_able_to_execute_allocation", /* E_VF_CANT_ALLOC */
  "This_operation_requires_a_defined_voting_farm", /* E_VF_UNDEFINED_VF */
  "A_wrong_node_has_been_specified", /* E_VF_WRONG_NODE */
  "The_system_was_not_able_to_get_the_global_id", /* E_VF_GETGLOBID */
  "The_system_was_not_able_to_execute_CreateThread", /* E_VF_CANT_SPAWN */
  "The_system_was_not_able_to_execute_ConnectLink", /* ConnectLink error */
  "The_system_was_not_able_to_execute_RecvLink", /* E_VF_RECVLINK */
  "The_system_was_not_able_to_perform_broadcasting", /* E_VF_BROADCAST */
  "Invalid_output(LinkCB_t*)_can't_deliver", /* E_VF_DELIVER */
  "Duplicated_input_message", /* E_VF_BUSY_SLOT */
  "Invalid_voting_farm_id", /* E_VF_WRONG_VFID */
  "Invalid_metric_function_pointer", /* E_VF_WRONG_DISTANCE */
  "Inconsistent_voting_farm_object", /* E_VF_INVALID_VF */
  "No_local_voters---one_voter_has_to_be_specified", /* E_VF_NO_LVOTER */
  "More_than_one_local_voter_has_been_specified", /* E_VF_TOO_MANY_LVOTER */
  "A_wrong_number_of_messages_has_been_specified", /* E_VF_WRONG_MSG_NB */
  "The_system_was_not_able_to_execute_SendLink", /* E_VF_SEDLINK */
  "Inconsistency_in_the_size_of_the_input_message", /* E_VF_INPUT_SIZE */
  "This_operation_requires_a_described_voting_farm", /* E_VF_UNDESCRIBED */
  "This_operation_requires_an_active_voting_farm", /* E_VF_INACTIVE */
  "Inconsistency_in_sender_unknown", /* E_VF_UNKNOWN_SENDER */
  "Time-out_reached_during_a_Select()", /* E_VF_EVENT_TIMEOUT */
  "A_Select()_returned_an_index_out_of_range", /* E_VF_SELECT */
  "Algorithm_Id_out_of_range", /* E_VF_WRONG_ALGID */
  "NULL_in_a_call-by-reference_pointer", /* E_VF_NULLPTR */
  "Maximum_number_of_opened_voting_farms_exceeded", /* E_VF_TOO_MANY */
};

void VF_perror(void)
{
  static char *VFN = "VF_perror";
  if (VF_error) {
    fprintf(stderr, "Error_condition_number_%d_raised_while_in_function_%s:_%s\\\"%s\\\"\\n",
      VF_error, VFN, errors[-VF_error]);
    fflush(stderr);
  }
}
```

This code is used in section 1.

**52.** The functions stored in the *DoVoting* array are defined here.

```

⟨ Voting Functions 52 ⟩ ≡
  ⟨ Exact Consensus 54 ⟩
  ⟨ Majority Voting 55 ⟩
  ⟨ Median Voting 56 ⟩
  ⟨ Plurality Voting 57 ⟩
  ⟨ Weighted Averaging 58 ⟩
  ⟨ Simple Majority Voting 53 ⟩
  ⟨ Simple Average 60 ⟩

```

This code is used in section 29.

**53.** The simplest algorithm, apart from exact consensus—counts the agreement and returns the widest.

```

⟨ Simple Majority Voting 53 ⟩ ≡
  static void VFA_SimpleMajorityVoting(VotingFarm_t *vf, void *inp[], int len, vote_t *vote)
  {
    int i, j;
    int n = vf->N;
    int v[VF_MAX_NTS];
    int threshold;

    threshold = n >> 1; /* n/2; */
    for (i = 0; i < n; i++) v[i] = 0;
    for (i = 0; i < n; i++)
      for (j = 0; j < n; j++)
        if (i ≠ j) {
          if (vf->distance(inp[i], inp[j]) < VFD_EPSILON) {
            v[i]++;
          }
        }
    for (i = 0; i < n; i++)
      if (v[i] ≥ threshold) {
        vote->outcome = VF_SUCCESS;
        memcpy(vote->vote, inp[i], len);
        return;
      }
    vote->outcome = VF_FAILURE;
  }

```

This code is used in section 52.

**54.** Exact consensus means perfect, bitwise equality.

$\langle \text{Exact Consensus } 54 \rangle \equiv$

```
static void VFA_ExactConsensus(VotingFarm_t *vf, void *inp[], int len, vote_t *vote)
{
    int i;
    int n = vf->N;
    if (inp[0] == 0) {
        vote->outcome = VF_FAILURE;
        return;
    }
    for (i = 1; i < n; i++) {
        if (inp[i] == 0) {
            vote->outcome = VF_FAILURE;
            return;
        }
        if (memcmp(inp[0], inp[i], len) != 0) {
            vote->outcome = VF_FAILURE;
            return;
        }
    }
    vote->outcome = VF_SUCCESS;
    memcpy(vote->vote, inp[0], len);
}
```

This code is used in section 52.

**55. Generalized Voters.** Several commonly used voting techniques have been generalized in [10] to “arbitrary  $N$ -version systems with arbitrary output types using a metric space framework”, including:

- formalized majority voter (**VFA\_MAJORITY**; cf. [10, §2.1, pp.445–446]),
- generalized median voter (**VFA\_MEDIAN**; cf. [10, §2.2, p.447]),
- formalized plurality voter (**VFA\_PLURALITY**; cf. [10, §2.3, pp.447–448]), and the
- weighted averaging technique (**VFA\_WEIGHTED\_AVG**; cf. [10, §2.4, p.448]).

All these techniques are based on the concept of “metric space” which is now recalled:

A metric space is a couple  $(X, d)$ , where  $X$  is the output space of the voting threads and  $d$  is a real value function defined on  $X \times X$  which is able in some way to “compare” two objects belonging to  $X$ ; more precisely,  $d$  behaves as a “distance” measure of any two objects in  $X$ . More formally,  $\forall(x, y, z) \in X^3$  the following properties hold:

1.  $d(x, y) \geq 0$  (distances are positive numbers or zeroes);
2.  $d(x, y) = 0 \Rightarrow x = y$  (different points have positive distances);
3.  $d(x, y) = d(y, x)$  (distances obey the reflexive property);
4.  $d(x, z) \leq d(x, y) + d(y, z)$  (two consecutive segments are greater than the segment that straightly connects their loose ends, unless the three points lie on the same straight line;)

then  $d$  is called a “metric”.

In other words, a metric is a function which is able to compare any two input objects and is able to numerically express a degree of “closeness” between them. [10] shows how four different voting algorithms can be executed starting from such a function. It is the user responsibility to supply a valid metric function on the call to *VF\_open*: that function shall get two pointers to opaque objects, compute a “distance”, and return that value as a positive real number.

These functions take advantage of the *Stack* class which has been used in order to mimic the list operations in the algorithms in [10].

$\langle$  Majority Voting 55  $\rangle \equiv$

```
static void VFA_MajorityVoting(VotingFarm_t *vf, void *inp[], int len, vote_t *vote)
{
    int i;
    int n = vf->N;
    int v;
    cluster_t *c;
#ifdef STATIC
    c = calloc(n, sizeof(cluster_t));
#else
    c = st_clusters;
    memset(c, 0, n * sizeof(cluster_t));
#endif
     $\langle$  Create a partition of blocks which are maximal with respect to the metric property 59  $\rangle$ 
    /* v is set by <Create a partition...> to the cardinality of the partition */
    for (i = 0; i < v; i++) {
        if (c[i].item_nr > n/2) {
            vote->outcome = VF_SUCCESS;
            memcpy(vote->vote, c[i].item, len);
            return;
        }
    }
    vote->outcome = VF_FAILURE;
}
```

This code is used in section 52.



**56.** “Generalized Median Voter”, §2.2 of [10, p.447]. See also the “mid-value select” technique in [9, p.60]

```

#define PRESENT 1
#define NOT_PRESENT 0
⟨Median Voting 56⟩ ≡
static void VFA_MedianVoting(VotingFarm_t *vf, void *inp[], int len, vote_t *vote)
{
    void *inputs[VF_MAX_NTS];
    value_t *v;
    int i, j;
    int ri, rj;
    double max, dist;
    int n, card;
#ifndef STATIC
    static char *VFN = "VFA/MedianVoting";
#endif
#ifdef STATIC
    v = st_VFA_v;
#else
    v = (value_t *) malloc(len * sizeof(value_t));
    if (v ≡ Λ) {
        LogError(EC_ERROR, VFN, "Memory_Allocation_Error.");
        VF_error = E_VF_CANT_ALLOC;
        return;
    }
#endif
    /* STATIC */
    for (n = vf→N, i = 0; i < n; i++) {
        v[i].object = inp[i];
        v[i].status = PRESENT;
    }
    ri = rj = 0;
    do {
        for (card = i = 0, max = -1.0; i < n; i++) {
            if (v[i].status ≡ PRESENT) {
                inputs[card++] = v[i].object;
                for (j = i + 1; j < n; j++) {
                    if (v[j].status ≡ PRESENT)
                        if ((dist = (vf→distance)(v[i].object, v[j].object)) ≥ max) {
                            max = dist;
                            ri = i;
                            rj = j;
                        }
                }
            }
        }
        if (max ≠ -1.0) {
            v[ri].status = v[rj].status = NOT_PRESENT;
        }
    } while (card > 2);
    vote→outcome = VF_SUCCESS;
    memcpy(vote→vote, inputs[0], len);
}

```

This code is used in section 52.

57. “Formalized Plurality Voter”, §2.3 of [10, p.447].

⟨ Plurality Voting 57 ⟩ ≡

```
static void VFA_PluralityVoting(VotingFarm_t *vf, void *inp[], int len, vote_t *vote)
{
    int i, j;
    int n = vf->N;
    int v;
    int max;
    cluster_t *c;
#ifdef STATIC
    c = calloc(n, sizeof(cluster_t));
#else
    c = st_clusters;
    memset(c, 0, n * sizeof(cluster_t));
#endif
    if (c ≡ Λ) LogError(EC_MESS, "Plurality", "c_is_NULL");
    ⟨ Create a partition of blocks which are maximal with respect to the metric property 59 ⟩
#ifdef VFDEBUG
    LogError(EC_MESS, "Plurality", "Partition_has_been_created.");
#endif
    j = -1;
    for (max = i = 0; i < v; i++) {
        if (c[i].item_nr > max) j = i, max = c[i].item_nr;
    }
#ifdef VFDEBUG
    LogError(EC_MESS, "Plurality", "Max_computed.");
#endif
    if (max > 1) {
        vote->outcome = VF_SUCCESS; /* memcpy(vote->vote, c[i].item, len); */
        memcpy(vote->vote, c[j].item, len);
    }
    else vote->outcome = VF_FAILURE;
#ifdef STATIC
    free(c);
#endif
}
```

This code is used in section 52.

**58.** “Weighted Averaging Technique”, §2.4 of [10, p.448]. The *ScalingFactor* variable is used for computing a set of “weights”, defined as follows: given  $n$  values,  $x_1, x_2, \dots, x_n$ , then

$$\forall i \in \{1, 2, \dots, n\} : w_i = \left[ 1 + \frac{\prod_{j=1, j \neq i}^n \mathbf{d}^2(x_j, x_i)}{a} \right]^{-1}$$

where  $a$  is equal to *ScalingFactor* and  $\mathbf{d}$  is the metric. Considered  $S = \sum_{i=1}^n w_i$ , the voted value is computed as  $x = \left( \frac{\sum_{i=1}^n w_i}{S} \right) x_i$  which is of course here computed as  $\frac{\sum_{i=1}^n w_i x_i}{S}$ .

$\langle \text{Weighted Averaging 58} \rangle \equiv$

```
static void VFA_WeightedAveraging(VotingFarm_t *vf, void *inp[], int len, vote_t *vote)
{
    int i, j;
    int n = vf->N;
    double *sum;
    double *weight, wsum;
    double *squaredist;
    double partial, f;
    int r, c;
    static char *VFN = "WeightedAveraging";
#ifdef STATIC
    sum = &st_VFA_sum;
    weight = st_VFA_weight;
    squaredist = st_VFA_squaredist;
#else
    sum = malloc(sizeof(double));
    weight = (double *) malloc(n * sizeof(double));
    squaredist = (double *) malloc(n * n * sizeof(double));
#endif /* STATIC */
    if (sum == Λ ∨ weight == Λ ∨ squaredist == Λ) {
        LogError(EC_ERROR, VFN, "Memory_Allocation_Error.");
        VF_error = E_VF_CANT_ALLOC;
        return;
    }
    if (ScalingFactor == 0) {
        LogError(EC_MESS, VFN, "Illegal_scaling_factor_---_set_to_1");
        ScalingFactor = 1.0;
    } /* compute the distances */
    for (i = 0; i < n; i++)
        for (j = 0; j < i; j++) {
            f = (vf->distance)(inp[i], inp[j]);
            squaredist[i * n + j] = f * f;
        }
    for (wsum = 0.0, i = 0; i < n; i++) {
        partial = 1.0;
        for (j = 0; j < n ∧ j ≠ i; j++) {
            if (i < j) r = j, c = i;
            else r = i, c = j;
            partial *= squaredist[r * n + c];
        }
        partial /= (ScalingFactor * ScalingFactor);
        wsum += weight[i] = 1.0 / (1.0 + partial);
    }
}
```

```

    }
    for (*sum = 0.0, i = 0; i < n; i++) {
        *sum += (*(double *) inp[i]) * weight[i];
    }
    if (wsum ≠ 0) {
        *sum /= wsum;
        vote→outcome = VF_SUCCESS;
        memcpy(vote→vote, sum, len);
    }
    else vote→outcome = VF_FAILURE;
#ifndef STATIC
    free(sum);
    free(weight);
    free(squaredist);
#endif
}

```

This code is used in section 52.

**59.** The input values are partitioned into a set of blocks,  $V_1, V_2, \dots, V_n$ , such that for each  $i$  block  $V_i$  is maximal with respect to the property that

$$\forall(x, y) \in V_i \times V_i : \mathbf{d}(x, y) \leq \epsilon,$$

where  $\mathbf{d}$  is the metric.

In order to reproduce as much as possible the algorithmic formalism of [10] we decided

- to mimic their Lisp-like statements with stacks, and
- to use **goto** statements.

In this way actions (1)–(6) in [10, p. 445–446] can be (more or less) mapped into the statements corresponding to labels *one* to *six* that follow.

⟨ Create a partition of blocks which are maximal with respect to the metric property 59 ⟩  $\equiv$

```
{
  char vt;
  char *del;
  void *item;
  int i, j, item_nr;
  vt = GET_ROOT()→ProcRoot→MyProcID;
#ifdef STATIC
  del = calloc(n, 1); /* alloc + set all of them to NO */
#else
  del = st_chars;
  memset(del, 0, n);
#endif
  for (v = i = 0; i < n; i++) {
    if (del[i]) continue;
    item = inp[i];
    del[i] = YES;
    c[v].item = item;
    for (item_nr = 1, j = i + 1; j < n; j++) {
      if (¬del[j] ∧ vf→distance(item, inp[j]) < ε) {
        del[j] = YES;
        item_nr++;
      }
    }
    c[v].item_nr = item_nr;
    v++;
  }
#ifdef STATIC
  free(del);
#endif
}
```

This code is used in sections 55 and 57.

**60.** Simple Averaging may be useful e.g., to “melt together”  $n$  sample values of a same pixel of an image. Of course it requires the objects are numbers. For the time being, the computation is performed in double precision floating point arithmetics. A problem of this technique is that it assumes the samples are not faulty, in the sense that they do not differ too much from each other: an enormously different addendum would cause the average to differ as well from the “correct” values. The weighted averaging technique is a partial solution to this.

⟨ Simple Average 60 ⟩ ≡

```
static void VFA_SimpleAverage(VotingFarm_t *vf, void *inp[], int len, vote_t *vote)
{
    int i;
    int n = vf->N;
    double *sum;
    static char *VFN = "SimpleAverage";
#ifdef STATIC
    sum = &st_VFA_sum;
#else
    sum = malloc(sizeof(double));
    if (sum == Λ) {
        LogError(EC_ERROR, VFN, "Memory_Allocation_Error.");
        VF_error = E_VF_CANT_ALLOC;
        return;
    }
#endif /* STATIC */
    for (*sum = 0.0, i = 0; i < n; i++) {
        *sum += (*(double *) inp[i]);
    }
    if (n == 0) {
        LogError(EC_ERROR, VFN, "Inconsistency---farm_cardinality_should_be_zero.");
        VF_error = E_VF_INVALID_VF;
        return;
    }
    *sum /= n;
    vote->outcome = VF_SUCCESS;
    memcpy(vote->vote, sum, len);
#ifdef STATIC
    free(sum);
#endif /* STATIC */
}
```

This code is used in section 52.

**61.** This means:

- send a message to the server telling it “connect me to the Agent (thread id 1)”
- do a *ConnectLink* with the Agent
- send a set up message to the Server so that it propagates that message to the Agent.

⟨ Ask the Server to set up a connection to an Agent 61 ⟩ ≡ /\* yet to be implemented \*/

This code is used in section 30.

**62. Closings.** This document and source code describes the actual implementation of the Voting Farm Tool as it appears in the EFTOS [1, 2] Basic Functionality Set Library. It has been crafted by means of the CWEB system of structured documentation [3].

**63. Index.** Here is a list of the identifiers used, and where they appear. Underlined entries indicate the place of definition. Error messages are also shown.

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